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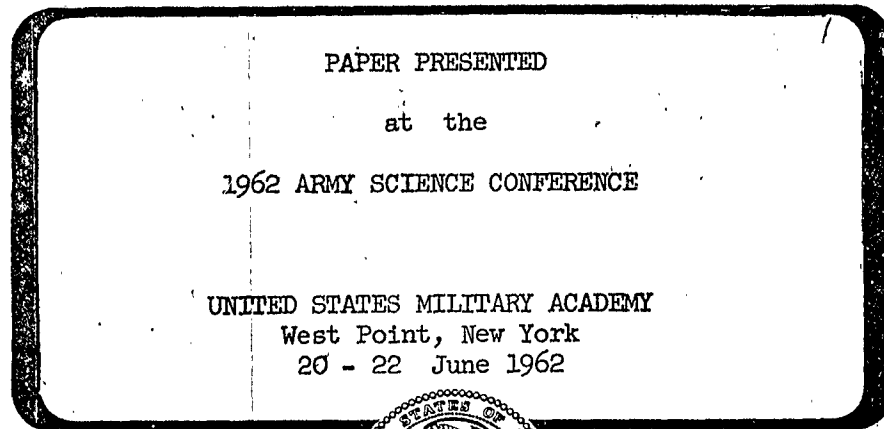
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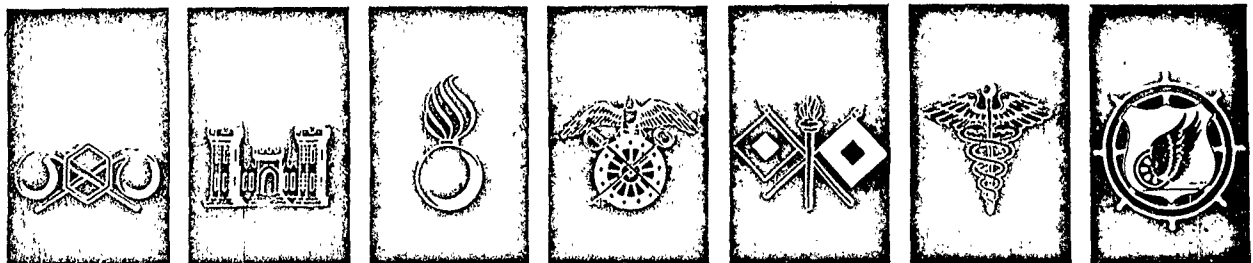
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TITLE: Tracer Studies of Vitamin C Utilization in Men; Metabolism of D-Glucuronolactone-6-C¹⁴, D-Glucuronic-6-C¹⁴ Acid and L-Ascorbic-1-C¹⁴ Acid

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ABSTRACT: Studies of body composition and the use of C¹⁴ isotopes has resulted in a method for stating the actual utilization of ascorbic acid by healthy men. After ingesting a single 20 µc quantity of D-glucuronolactone-6-C¹⁴, the urine of healthy men contains C¹⁴ activity which can be isolated and found in the highly purified phenylhydrazine derivative of ascorbic acid. Such activity is not found following the ingestion of D-Glucuronic-6-C¹⁴ acid, indicating that the above lactone, but not its acid can function as a source of ascorbic acid. In subjects who ingest 20 µc of L-ascorbic-1-C¹⁴ acid, the daily urinary oxalate arising from metabolism of the labeled ascorbate is subsequently excreted as a constant proportion of the total C¹⁴ activity remaining in the body. Thus it can be inferred that the portion of the daily oxalate which arises from metabolism of ascorbate is formed and excreted at a constant rate. Further, in 6 men of diverse body weight and degree of fatness, it was found that the ascorbate utilization, as expressed in terms of C¹⁴ oxalate excretion, occurred at a rate of 0.207 mg/day/kg of fat-free body weight. Rarely, if ever, do adult males exceed 90 kg in lean body mass. Therefore, 18 mg/day intake would match the greatest quantity of ascorbate metabolized by the largest healthy man.

BAKER, SAUBERLICH, WOLFSKILL and WALLACE

TRACER STUDIES OF VITAMIN C
UTILIZATION IN MEN; METABOLISM
OF D-GLUCURONOLACTONE-6-C¹⁴,
D-GLUCURONIC-6-C¹⁴ ACID AND
L-ASCORBIC-1-C¹⁴ ACID

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Recent studies (1) indicated that D-glucuronolactone caused increased blood ascorbic acid levels as well as increased urinary excretion of ascorbic acid in men, whereas D-glucuronic acid did not do this. To check the possible conversion of D-glucuronolactone to L-ascorbic acid, it was decided to study the metabolism of the lactone in two ways. One was to give D-glucuronolactone-6-C¹⁴ orally and then isolate urinary ascorbic acid to determine if any of the labeled lactone had been converted to L-ascorbic acid. The other was first to label the total body ascorbic acid pool with L-ascorbic-1-C¹⁴ acid and then test with various loads of D-glucuronolactone to see if any changes would take place in the specific activity and rate of excretion of ascorbic acid. Further, an attempt was made to see if the total body ascorbic acid and its rate of utilization were related to the fat-free body weight.

Experimental. The D-glucuronolactone-6-C¹⁴ and D-glucuronic-6-C¹⁴ acid were obtained from the National Bureau of Standards, Washington, D. C. The L-ascorbic-1-C¹⁴ acid was obtained from the California Corporation for Biochemical Research, Los Angeles, California. These compounds were checked for purity prior to use by melting point measurement and by paper chromatography. The activity of the above compounds was checked by radioassay. D-glucuronolactone-6-C¹⁴, 4.11 μ c/mg, or D-glucuronic-6-C¹⁴ acid, 3.72 μ c/mg, were freshly dissolved in distilled water and swallowed immediately by healthy men in quantities of 20 μ c of each appropriate compound for each man together with a cold carrier load of 2 g of D-glucuronolactone or D-glucuronic acid. For the men receiving L-ascorbic-1-C¹⁴ acid, each swallowed 20 μ c of L-ascorbic-1-C¹⁴ acid having a specific activity of 1.35 mc/mM. No cold carrier was given to these subjects. Following this, each man swallowed 2 g of freshly dissolved D-glucuronolactone on the 3rd or 9th day.

Total daily urine was collected and measured from all subjects; these samples were refrigerated and 2.0 ml of each were taken for counting.

Immediately after receiving the tracer quantity of D-glucuronolactone, D-glucuronic acid or L-ascorbic acid, the men were made to expire directly through a CaCl_2 drying train into a 5-liter Cary-Tolbert ionization chamber connected to a vibrating reed electrometer. The C^{14}O_2 activity, total CO_2 , and the volume of flow were recorded automatically on a 6-channel recorder.

The total activity of each urine sample was determined by use of a liquid scintillator counter using P-dioxane-toluene. Oxalate in selected samples was isolated as calcium oxalate, recrystallized 4 times, and dissolved in 1 N hydrochloric acid for counting in the liquid scintillator. Quantitative determination of the total oxalate was done with the Archer method (2). Efficiencies for all liquid scintillator counting samples were determined individually by use of added standard C^{14} samples.

Urinary ascorbic acid levels were chemically determined by the Schaffert method (3). The urinary ascorbic acid was then isolated by the method described by Jackel et al. (4). After the dinitrophenylhydrazone (DNPH) derivatives were recrystallized, these were dissolved in P-dioxane and applied to weighed planchets and counted in a gas flow counter. All DNPH derivatives were recrystallized to constant activity which usually required 4 to 6 recrystallizations.

Total body tissue volume (V) was estimated in duplicate tests using a body volumeter based on displacement of water (5). From body weight (M) and V, fat (F) in kg was calculated according to an equation developed in this laboratory: $F = 4.834 V - 4.366 M$.

Results. Figure 1 shows the rate of C^{14}O_2 expiration in 3 men, as measured with an ionization chamber electrometer immediately following the swallowing of 20 μc of D-glucuronolactone-6- C^{14} or D-glucuronic-6- C^{14} acid. The cumulative excretion of C^{14}O_2 after ingestion of D-glucuronolactone was 44% of the total carbon-14 dose in 2 experiments, whereas after ingestion of D-glucuronic acid it was 68%. The peak rate of excretion occurred within 25 minutes in the lactone experiments, whereas in the glucuronic acid experiments it did not occur until after the 4th hour following ingestion. No C^{14}O_2 activity could be detected in the expired air of the subjects receiving L-ascorbic-1- C^{14} acid even using a 15-liter ionization chamber for greater sensitivities. A fraction of 1% oxidation to CO_2 during the first 8 hours could have been easily detected by this technique.

The urinary ascorbic acid which was isolated as the DNPH derivative had no radioactivity in the labeled D-glucuronic acid

experiments on 2 men. However, the DNPH derivatives isolated from the urinary ascorbic acid of the 3 men who had received D-glucuronolactone-6-C¹⁴, the specific activities ranged from 2.1×10^{-3} to 3.6×10^{-3} $\mu\text{c}/\text{mg}$ ascorbic acid. This, of course, was dependent upon the amount of ascorbic acid excreted daily which ranged from 26.4 to 39.0 mg.

Further, an experiment was made with 20 μc of D-glucuronolactone-6-C¹⁴ added to freshly voided urine together with cold carrier D-glucuronolactone and L-ascorbic acid. From this mixture the ascorbic acid was isolated as the DNPH derivative, recrystallized at least 4 times, and counted to determine the degree of contamination, if any, by the C¹⁴ labeled lactone. Less than 0.04% of the initial 20 μc could be detected in the ascorbate derivative, indicating that in the experiments on ingestion of D-glucuronolactone-6-C¹⁴ that less than 10% of the ascorbate derivative activity could have been from contamination under the most un auspicious set of conditions.

Figure 2 shows the percent of total activity excreted in the urine as oxalate from one of 2 men who had received 20 μc of L-ascorbic-1-C¹⁴ acid. This was done to see if the oxalate excretion arising from the C¹⁴ ascorbate was constant and, further, to study the effect of cold D-glucuronolactone, D-glucuronic acid, and L-ascorbic acid on the oxalate and ascorbic acid excretion. The oxalate activity was, indeed, remarkably constant, remaining at a level of 50 to 52% of the total activity excreted and changed only when the body ascorbate pool was overloaded or otherwise affected. Both subjects, who received cold D-glucuronolactone on the 3rd or 9th day following the L-ascorbic-1-C¹⁴ acid, excreted less total urinary oxalate activity whereas the urinary ascorbate total activity increased and was of a lowered specific activity. On the following day, the excretion of oxalate radioactivity returned to the 50% level. On the 2nd day following overloading with the cold lactone, the proportion of the total radioactivity excreted in the form of oxalate decreased, for unknown reasons, and did not return to the 50% level until after a further 2 days. Also shown (Figure 2) is a similar effect exhibited by overloading with 0.5 g of cold L-ascorbate. Further, note that 2 g of cold D-glucuronic acid, if anything, caused increased oxalate excretion. The above effects, at the least, indicate a marked dilution of the body ascorbate pool presumably by ascorbate arising from glucuronolactone.

The half-life of the L-ascorbic acid was 16 days in the 3 subjects receiving labeled ascorbate. This was obtained by plotting the percent of the initial dose remaining in the body as a logarithmic function of time. An average biological half-life of 16 days for ascorbic acid has been reported to occur in 3 diseased patients (6).

Table I shows the body pool size of ascorbic acid in 5 men. To calculate this, the specific activity of urinary ascorbic acid

(Column 1) was divided into the total activity remaining in the body at the end of the collection period (Column 2) to obtain the total body ascorbic acid (Column 3). In the last 3 tests the pool size was estimated by assuming that one-fourth of the C^{14} labeled D-glucuronolactone supplied ascorbic acid which, in turn, was incorporated into the ascorbic acid pool. On Subject No. 2 the estimated pool size was 1.65 g compared with 1.64 g when this subject was measured using L-ascorbic-1- C^{14} acid, thus showing that, indeed, one-fourth of the lactone went to ascorbate.

From comparison of Columns 4 and 5 of Table I, it appears as though the fat-free body weight contains a uniform proportion of ascorbic acid in the quantity of 33.3 mg/kg. Further, as seen in Figure 3, the rate of utilization of ascorbic acid also is directly related to the fat-free body weight. The utilization rate was obtained from 2 assumptions: 1) sufficient time had elapsed for the C^{14} labeled ascorbic acid to become uniformly distributed in the body and 2) the proportion of excreted oxalate- C^{14} arising from labeled ascorbic acid was constant. The rate of utilization was obtained by dividing the specific activity of the ascorbic acid into the total activity excreted as oxalate during the 24-hour collection period. As an example, in the case of Subject I, 0.112 μ c/day was present as oxalate and the specific activity of the ascorbate isolated that day was 0.0078 μ c/mg ascorbic acid, giving a rate of 14.4 mg ascorbic acid utilized on that day. The same subject who, on the 3rd day had received 500 mg of cold ascorbic acid, continued to show an ascorbate utilization of only 15.0 mg/day.

Discussion. Studies of body composition and the use of C^{14} isotopes has here resulted in a method for stating the actual utilization of ascorbic acid by healthy men. After ingesting a single 20 μ c quantity of D-glucuronolactone-6- C^{14} , the urine of healthy men contains C^{14} activity which can be isolated and found in the highly purified phenylhydrazine derivative of ascorbic acid. Such activity is not found following the ingestion of D-glucuronic-6- C^{14} acid, indicating that the above lactone, but not its acid, can function as a source of ascorbic acid.

In subjects who ingest 20 μ c of L-ascorbic-1- C^{14} acid, the daily urinary oxalate arising from metabolism of the labeled ascorbate is subsequently excreted as a constant proportion of the total C^{14} activity remaining in the body. Thus, it can be inferred that the portion of the daily oxalate which arises from metabolism of ascorbate is formed and excreted at a constant rate. Note, since Crawhall et al. (7) showed that about 40% of the daily oxalate came from breakdown of glycine and here it is shown that another 50% comes from ascorbate, it is possible to speculate that nearly all of the urinary oxalate comes from the metabolism of glycine and ascorbate.

The ingestion of a single, comparatively large 0.5 g quantity of "cold" ascorbic acid or its precursors by a subject whose

body ascorbic acid pool has been previously labeled, as described above, results in increased excretion of C^{14} ascorbate of lowered specific activity. These effects are transitory in that within 2 days the total ascorbate excretion returns to previous levels and the ascorbate specific activity is lower than it was prior to dilution of the body ascorbate pool.

Simultaneously, the total activity and the specific activity of the oxalate decreases, but the proportionality of the total oxalate activity to the specific activity of the ascorbate remains the same. From these effects, it can be inferred that the utilization breakdown of ascorbic acid in the body occurs at a constant rate irrespective of an increased rate of supply of ascorbate to the body.

Further, in 6 men of diverse body weight and degree of fatness, it was found that the ascorbate utilization, as expressed in terms of C^{14} oxalate excretion, occurred at a rate of 0.207 mg per day per kilogram of fat-free body weight. Rarely, if ever, do adult males exceed 90 kg in lean body mass. Therefore, 18 mg per day intake would match the greatest quantity of ascorbate metabolized by the largest healthy man.

Summary

1. Results of studies with healthy men revealed that close to one-fourth of D-glucuronolactone-6- C^{14} was converted to L-ascorbic acid whereas, on the other hand, no activity could be detected in the ascorbate derivative isolated from the urine of subjects receiving D-glucuronic-6- C^{14} acid.
2. One-half of the urinary oxalate arises from the breakdown of ascorbic acid and is excreted at a constant rate.
3. The size of the ascorbic acid pool and its rate of utilization was directly related to the size of the fat-free body weight.

TABLE I. Body Ascorbic Acid in Healthy Men

Subject	Day of collection*	(1) Specific activity of urinary ascorbic acid $\mu\text{c}/\text{mg}$	(2) Activity remaining at end of collection μc	(3) Total body ascorbic acid mg	(4) Total body ascorbate Body wt mg/kg	(5) Total body ascorbate Fat-free body wt mg/kg
1	1	0.0077	18.61	2416	29.4	34.0
2	3	0.0079	12.95	1640	20.5	32.9
3	1	0.0110	20.04	1823	29.7	34.4
4	1	0.0021	18.50	$\left(\frac{8800}{4}\right) 2200^{\dagger}$	22.5	34.0
5	1	0.0036	18.70	$\left(\frac{5200}{4}\right) 1300^{\dagger}$	27.6	31.8
2	1	0.0028	18.00	$\left(\frac{6600}{4}\right) 1650^{\dagger}$	20.5	32.9

* All collections were for 24 hours except Subject No. 3 which was for 8 hours.

\dagger Assuming 25% conversion of D-glucuronolactone-6- Cl^{14} to body ascorbic acid. Subjects 1, 3 and second test on Subject 2: L-ascorbic-1- Cl^{14} acid. Subjects 4, 5 and first test on Subject 2: D-glucuronolactone-6- Cl^{14} .

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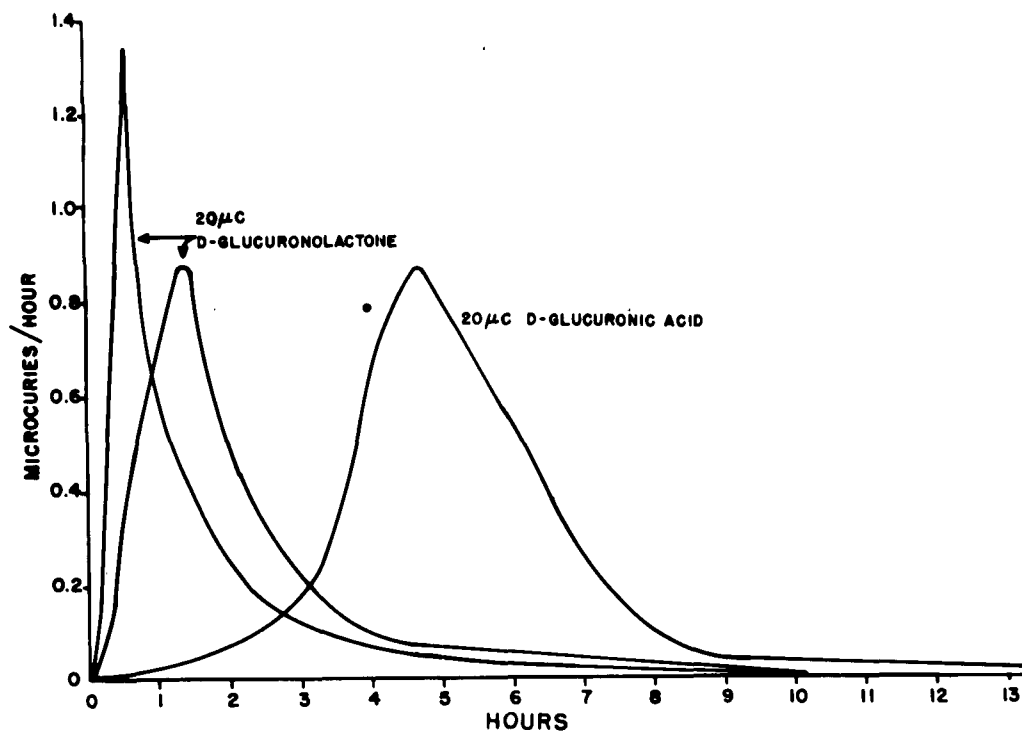


Fig. 1. Rate of $C^{14}O_2$ expiration following ingestion of 20 μ C quantities of D-glucuronolactone-6- C^{14} and D-glucuronic-6- C^{14} acid.

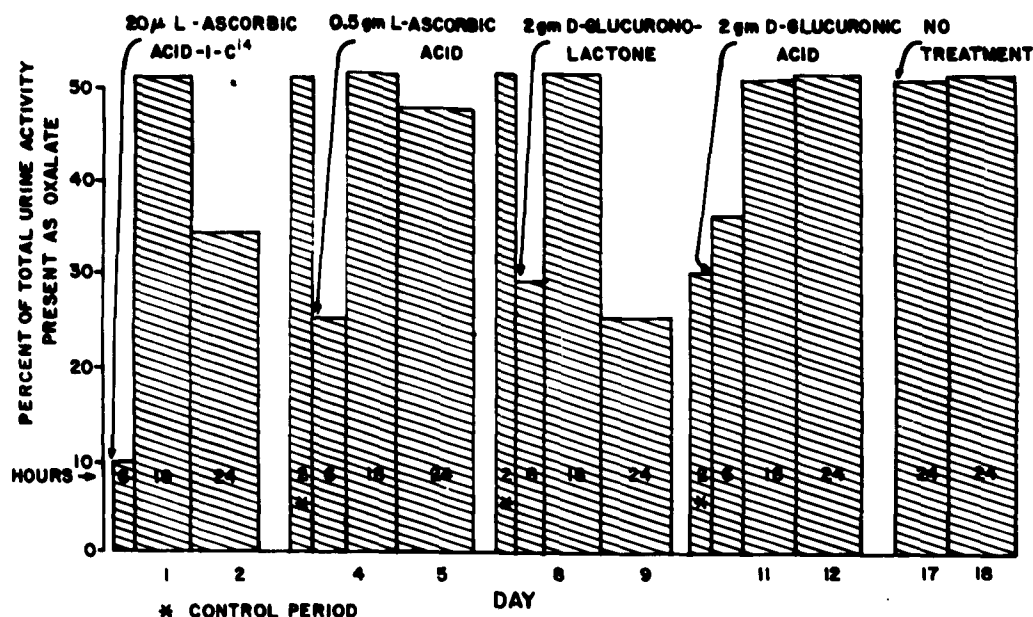


Fig. 2. Percent of total activity excreted by the kidneys as oxalate in Subject No. 1 on the days following ingestion of 20 µ of L-ascorbate-1-C¹⁴. The hours of duration of each collection period are indicated in each block of the figure. See text for indicated treatments.

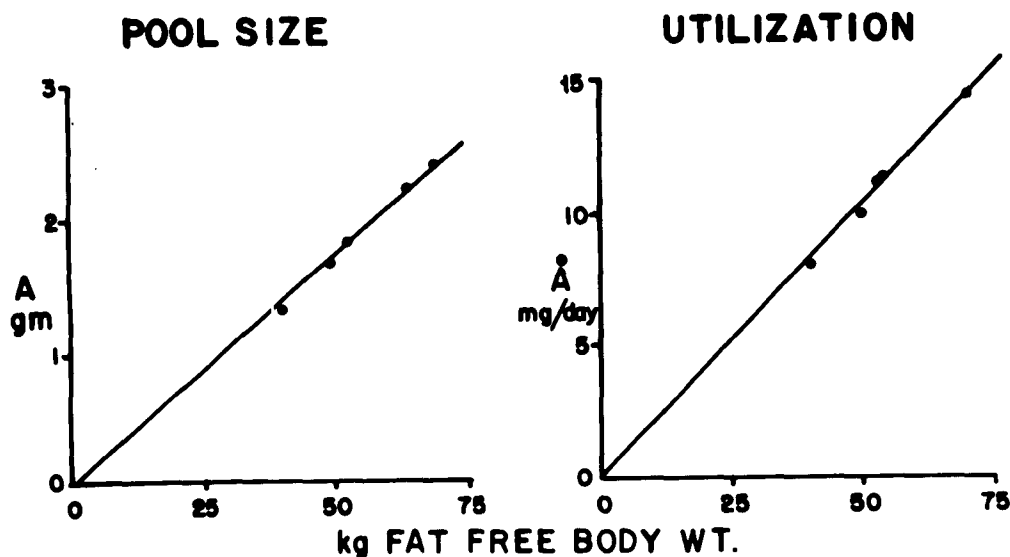


Fig. 3. Total body ascorbic acid and its rate of utilization are directly related to fat-free body weight of healthy men.